

A Comprehensive Review of Speed Control Mechanisms for Smart Electric Tricycles & Wheelchairs: Challenges, Advances and Future Directions

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Abstract – The rise of smart mobility solutions has brought noticeable improvement in the assistive technology, enabling greater autonomy and independence for elderly and disabled individuals in their mobility. Among these innovations, electrically powered wheelchairs and electric tricycles are important for improving independent mobility. Maintaining stability and safety during turning manoeuvres remains a dominant challenge, as uncontrolled speed variations can lead to instability, discomfort, and it has an increased risk of accidents. A systematic review of speed control strategies employed in electrically powered assistive devices, with a focus on improving maneuverability and safety at turning locations is presented in this paper. The review presents a deep analysis of different conventional and advanced control methods, which includes proportional-integral-derivative (PID) controllers, fuzzy logic systems, adaptive control mechanisms, and artificial intelligence (AI) models. Furthermore, recent advancements in sensor-based navigation, real-time feedback mechanisms, and Internet of Things (IoT)-enabled predictive algorithms have been critically analysed. This study presets a novel approach to combine sensor fusion, machine learning algorithms, and adaptive braking mechanisms to enhance speed regulation at turning points. The suggested system dynamically adjusts speed on the basis of real-time data collected from gyroscopes, accelerometers, LiDAR sensors, and environmental recognition systems, thus optimizing maneuverability while avoiding accidental risks. By bridging the gap between traditional approaches and intelligent speed regulation systems, this review provides meaningful insights for researchers, engineers, and policymakers for the development of next-generation assistive mobility solutions that prioritize safety, efficiency, and user experience.

Keywords: Adaptive control, assistive mobility, electric tricycle, intelligent navigation, IoT-enabled predictive modelling, machine learning, real-time feedback, sensor fusion, smart powered wheelchair, speed control, turning safety

I. INTRODUCTION

The increasing global population of elderly and disabled has led to the need for smart and advanced assistive mobility solutions that ensures safety, autonomy and ease of use. Smart powered wheelchairs and electric tricycles have originated as key technologies, providing enhanced autonomy ultimately leading to a better-quality life for the users. Advanced mobility solutions like automated navigation, obstacle detection, and adaptive speed control enhances safety and user experience. However, one of the most long-term challenges in the working is ensuring safe and stable navigation while manoeuvring through turns. Uncontrolled change in speed while navigating turns may result in instability, discomfort, and increasing the chance of collisions [1]. According to World Health Organization statistics produced in 2024 approximately 15% of the global population has some form of disability, with mobility impairments being more common in elderly individuals [2]. Previous studies indicate that 45% of the accident using some mobility devices occur at turning locations [3], while 68% of users feels anxiety when moving through the sharp turns or corners [4], and 73% need some kind of assistance in deep turning situations [5]. This study emphasizes the urgent need for adaptive and intelligent speed control mechanisms that can help in enhanced stability and ease of movement by comparing the conventional and novel methods of manoeuvring which have not been reported so far.

Over the past few decades, speed regulation in assistive mobility devices has evolved significantly. The conventional wheelchairs relied on basic electronic control systems with manual speed adjustments and were not familiar to dynamic control environments. Latest developments introduced advanced sensor-based navigation systems, which helped in obstacle detection and speed controlling capabilities up to some extent. However, the used initially performed in a reactive manner and did not exhibit predictive control features. With the latest emerging AI-driven control mechanisms, modern smart wheelchairs and electric tricycles have now overcome the problem of lacking predictive features, thus exhibiting real time speed regulation, and learning through user behaviour. These developments greatly incorporate enhanced navigation, increasing the safety, and user confidence, specifically at turns. Table 1 analyses and provides a summary of research done so far along with the reported limitations in speed control technologies for assistive mobility devices:

TABLE 1. EVOLUTION OF SPEED CONTROL SYSTEMS (2005-2025)

Period	Technology	Key Features	Limitations
2005-2010	Basic Electronic Control	Simple speed adjustment, Manual turning control	Limited adaptation, No predictive features
2011-2015	Sensor-Based Systems	Obstacle detection, Basic speed modulation	Reactive only, Limited user customization
2016-2020	Smart Control Systems	User behaviour learning, Adaptive speed control	Complex interface, High cost
2021-2025	AI-Enhanced Systems	Predictive control, Real-time adaptation	Requires regular updates, Power intensive

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Conventional proportional-integral-derivative (PID) controllers, have been used widely in mobility assistive devices to ensure controlled movements [6]. However, these methods have noticeable limitations especially in adapting to dynamic environmental conditions, and different user inputs [7]. Thereupon, researchers have to investigate and explore alternative methodologies which are able to integrate real time feedback mechanisms including fuzzy logic-based controllers, AI-driven adaptive speed control, and sensor fusion techniques [8]. The latest advancements in AI and IoT have improved speed control systems in smart assistive mobility devices. AI-based models enable real-time speed control on the basis of feedback by the user and environmental conditions, ultimately promising a controlled movement of the disabled [9]. IoT-based predictive systems use cloud computing and real-time sensor analysis to regulate speed control in an optimal manner before taking a turn, reducing risks associated with sudden speed changes [10]. Deep learning models were used to train the datasets providing the enhanced predictive control mechanisms allows to adjust the speed of the devices by analysing historical user behaviour and environmental conditions [11]. Moreover, the inclusion of LiDAR sensors, ultrasonic sensors, and inertial measurement units (IMUs) has significantly improved the precision of speed in mobility devices. LiDAR-based navigation systems detect obstacles and estimate the turning radius, enabling intelligent speed adjustments for smooth movements [12]. Along with this real-time edge computing has brought a significant improvement for processing sensor data with minimal latency, in-turn enhancing response times in speed alteration [13].

This paper presents a systematic review of speed control techniques employed in electrically powered smart wheelchairs and electric tricycles, analysing conventional and advanced methodologies for improving maneuverability at turning locations. The study critically evaluates PID controllers, fuzzy logic systems, adaptive control mechanisms, and AI-driven speed regulation models, while also investigating emerging trends such as sensor-based navigation, real-time feedback loops, and IoT-enabled predictive control.

II. SYSTEMATIC REVIEW OF SPEED CONTROL IN SMART WHEELCHAIRS AND E-TRIKES

Electrically powered assistive devices such as smart wheelchairs and electric tricycles have been widely accepted as the essential mobility options for the persons with disabilities. Ensuring the safety of the user it still the major challenge at turning locations. To improve the mobility option and decrease the risks of accidents there is a need of efficient speed control system. This research article complies with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards by applying methodical approach in order to conduct a detailed analysis of the existing methods. This review presents the clear approach how the speed control strategies are used in mobility devices which are electrically powered. The study selection summary is shown in Table 2.

TABLE 2. PRISMA-BASED LITERATURE SELECTION SUMMARY

Stage	Number of Studies
Identified Studies	300
Screened Studies	180
Eligible Studies	80
Included Studies	52

The detailed analysis was made around key components such as the objectives of research, plans to collect the data, standards to select the study and methods to extract the data. Table 3 presents the summary of the review processes. The review process proposes some research questions focusing on determining the existing of speed control strategies. The first study aims to evaluate the prominent speed control methods in electric tricycles and smart wheelchairs specifically at turns. Secondly, the review examines how sensor-based and AI-based technologies are contributing in the safety and comfort in the available mobility options. Lastly, the reviews focus in identifying the limitations of the present research also highlights the potential improvements that will help in developing better speed control methods. Examining these research questions creates a way to understand the present approaches and mentioning the areas where further innovations is required.

In order to assure the relevancy of the studies presented in the research article the data collection was done rigorously. The research articles were collected from IEEE Xplore, Google Scholar, Taylor & Francis, PubMed and Open Access Journals. Recent advancements in the field of sensor-based navigation, AI-driven control systems, and adaptive braking methods are presented from the literature published during 2005-2025. Specific keywords like "smart wheelchair speed control," "e-trike adaptive speed," "AI in assistive mobility," and "sensor-based wheelchair navigation" were used to find the most relevant papers. In order to begin the analysis, the dataset has to be refined because of large numbers of papers that were gathered.

A clear selection criterion was applied in order to consider the paper with the relevant keywords for the analysis. Priority was given to the research based on AI-enhanced navigation, sensor-based adaptive control and speed regulation mechanisms. The research articles that failed to provide substantial technical contributions in the smart assistive mobility devices are excluded from the study. Also, the papers which did not clearly state the speed regulation of smart assistive mobility devices are eliminated. Using the above criteria, only the reliable and high-quality papers are considered in the analysis of the system. Once the selection of study is over, the data was extracted and arranged into categories to present the corresponding findings. The studies are arranged according to the key factors like control methods, technical progress and how do they connect with the real world.

TABLE 3. OVERVIEW OF REVIEW METHODOLOGY

Step	Description
Research Questions	Defined key research questions focusing on speed control methods, the role of AI-driven improvements and the limitations within current research.
Data Collection & Search Strategy	Sources: IEEE Xplore, Google Scholar, ScienceDirect, Springer, Taylor & Francis, PubMed. Timeframe: 2005-2025. Keywords used: smart wheelchair, speed control, e-trike adaptive speed, AI in assistive mobility and sensor-based wheelchair navigation.
Selection Criteria	Inclusion: Studies on speed control, AI-driven navigation, sensor-based adaptive control. Exclusion: Non-English papers, non-technical studies, duplicate studies, and papers without substantial technical contributions.
Data Extraction & Analysis	Categorization of studies based on control methodologies, innovations, and effectiveness. Comparative analysis conducted to assess advantages and limitations of different approaches.

III. COMPREHENSIVE ANALYSIS OF SMART ASSISTIVE DEVICES

A comprehensive analysis carried out to gather relevant studies on smart wheelchairs and e-trikes, which focused on advancements in AI-driven speed control mechanisms, adaptive braking, and sensor-based navigation. To select the most relevant studies, a deep analysis was done on the research published between 2005 to 2025 across multiple e-databases, including IEEE Xplore, Google Scholar, Taylor & Francis Online, PubMed, and Open Access journals. To refine the dataset and ensure high relevance, carefully chosen search keywords were used, targeting electric and powered wheelchairs, AI-enhanced smart wheelchairs, and assistive technology applications. The number of retrieved studies per keyword and database is presented in Table 4.

TABLE 4. DETAILS OF KEYWORDS SEARCHED FROM ELECTRONIC DATABASE

Search Keywords	IEEE Xplore	Google Scholar	Taylor & Francis Online	PubMed	Open Access Journals	Total
Electric Wheelchair and AI Techniques	150	1,200	80	60	100	1,590
Powered Wheelchair and Assistive Technology	200	1,500	100	75	120	1,995
Smart Wheelchair and Artificial Intelligence	180	1,300	90	65	110	1,745
Assistive Technology and AI-Based Control	170	1,400	85	70	115	1,840
Electric Wheelchair and Machine Learning	160	1,250	95	55	105	1,665
Total Articles Retrieved	860	6,650	450	325	550	8,835

A. Study Selection and Screening Process

To maintain methodological integrity, an inclusion-exclusion framework was applied to filter relevant studies. Research was included if it was published between 2005 and 2025, focused on AI-driven speed control, adaptive braking, and smart navigation in powered mobility devices, and provided technically significant contributions to assistive mobility. Excluded studies comprised non-English publications, research without experimental validation, and studies not directly addressing assistive mobility technologies. Following the initial dataset retrieval, duplicates were removed, and the remaining articles underwent a title and abstract screening to assess relevance. Full-text reviews were performed for studies meeting the inclusion criteria, leading to a final selection of high-impact research papers for in-depth analysis. This structured approach ensured that only rigorously vetted studies were included in the review.

B. Key Research Contributions and Technological Innovations

The refined selection of studies revealed several critical advancements in smart wheelchair control, AI-based navigation, and adaptive speed regulation. One study introduced a real-time gaze-controlled wheelchair, utilizing computer vision and advanced eye-tracking technology to interpret user intent for hands-free mobility. This innovation led to the significant improvement in enhancing accessibility for individuals with severe impairments, allowing for precise wheelchair control [14]. Another research effort focused on developing a cost-effective smart wheelchair that integrates Arduino Nano, IoT connectivity, and obstacle detection sensors. Advanced safety and adaptability are ensured by implementing voice control, joystick-based control, and fall detection parameters. This study detailed about the importance of adoption of smart wheelchair, particularly for individuals facing financial limitations [15].

Sumit et al. in his study “Advances in Smart Wheelchair Technology” highlighted the uses of advanced techniques like AI and robotics into traditional assistive mobility devices. The research categorized smart wheelchairs based on sensing technologies, user interfaces, and autonomous navigation capabilities. Findings revealed that collision avoidance, voice-controlled operation, and fully autonomous mobility solutions were among the most impactful advancements. However, the study also emphasized the necessity of designing user-friendly, cost-effective solutions to ensure wider accessibility and usability [16]. Cooper’s study on intelligent power wheelchair control traces the evolution from analog to microprocessor-based feedback systems, significantly improving speed regulation, directional stability, and safety. The integration of microcontrollers has allowed for

precise speed adjustments, user customization, and enhanced obstacle detection, but sensor accuracy and adaptability to diverse environments remain major challenges [17].

Further advancements in alternative wheelchair control systems were investigated by Alibhai et al., who introduced an electromyography (EMG)-based interface that enabled users to operate a wheelchair using forearm muscle signals. This study provided a promising alternative to traditional joystick-based control, particularly for individuals with limited hand dexterity. While the system demonstrated high accuracy in controlled environments, future improvements were suggested in enhancing outdoor performance and reducing signal interference [18].

To further explore the inexpensive navigation solutions, Tian et al. proposed a monocular vision-based guidance system utilizing Aruco marker detection. The system allowed for efficient indoor localization, enabling autonomous movement based on predefined visual markers. A budget-friendly alternative to laser-guided navigation was proposed but due to its dependency on fixed markers its applicability in dynamic and unstructured environments was limited [19]. Neural network-based adaptive control was proposed by Challoo et al., who focused on the development of a Neuro-Fuzzy controller to reduce the tremor-induced joystick inaccuracies in individuals with Multiple Sclerosis (MS). This study demonstrated the improvement in navigation by adaptive filtering of undesired hand movements. However, to maximize the performance researchers emphasized the on need of personalized assessment for each user to optimize performance [20].

Another major contribution was to analyse the impact of dynamic arm support (DAS) on power wheelchair (PWC) control for individuals with upper limb disabilities. Over a year, four individuals used the Kinova DAS O110 for a year, with one successfully integrating it, enhancing wheelchair skills and experiencing psychosocial advantages. Some faced the challenged like increased wheelchair width and device-related issues due to which they discontinued. The studies highlighted the importance of proper service delivery and environmental accessibility for successful DAS integration [21]. A multimodal control system for assistive robots was developed in this study to facilitate the people with disabilities and operate the wheelchair or e-trike and robotic arm using finger and chin joysticks. Customised accessibility provided effortless control, and user testing was done with ten participants who evaluated the performance under various conditions and circumstances. The system demonstrated high accuracy (~5 mm), low latency (4 ms), and reliable operation under different velocities and payloads (1-3.5 lbs). Tasks like picking and placing objects were completed with 100% success in under one minute, showcasing the system's potential to improve accessibility and independence in daily activities [22].

Martinazzo et al. present Motion Assistant, a Bluetooth-enabled, open-source wheelchair control module based on Arduino technology. The system is designed to reduce costs and increase accessibility, making smart wheelchairs more affordable in developing regions. However, hardware standardization and mass production pose challenges to commercial adoption, requiring further refinements to make the system compatible with industry regulations [23]. Brain-Computer Interfaces (BCIs) for EEG-based wheelchair control was explored by Ghasemi et al., in turn allowing the users with some disability to control and navigate using thought commands. This used the integration of electroencephalography (EEG) signal processing, which translated brain activity into accurate movement commands. This users with severe disabilities became more independent but a real time implementation and data processing issue needed to be addressed before its widespread implementation [24].

An extensive review was conducted by Kim et al. to thoroughly study the use of advanced techniques like BCI, EMG, deep learning, and autonomous navigation. According to the study reinforcement learning and intelligent control systems have the potential to improve wheelchair adaptability, although some major challenges were still persisting like the user privacy, need of extensive training to the users and the commercialization [25]. Dahmani et al. introduce an eye-tracking system for wheelchair control, using CNN-based gaze detection to translate eye movements into commands. This system provides a hands-free mobility solution for individuals with severe motor impairments. The study reports high accuracy (99.3%) in gaze detection, even in varying lighting conditions, but highlights the need for optimization in real-time processing and user adaptability to ensure widespread usability [26].

The reviewed studies demonstrate significant strides in AI-integrated speed control, adaptive navigation, and multimodal user interfaces for smart wheelchairs and e-trikes. However, challenges related to sensor accuracy, affordability, real-time processing delays, and regulatory compliance remain key barriers to widespread adoption. Future research should emphasize cost-effective solutions, optimized sensor integration, and improved real-time adaptability to develop next-generation intelligent mobility aids that are both accessible and efficient. Table 5 presents a comparative evaluation of core technologies based on critical operational parameters, while Table 6 outlines a detailed comparison of innovations, distinctive features, and the key challenges discussed across various research studies.

TABLE 5. COMPARATIVE ANALYSIS OF SPEED CONTROL METHODS IN SMART E-TRIKES OR WHEELCHAIRS

Control Method	Energy Efficiency	Terrain Suitability	Safety Feedback Mechanism	Affordability	Real-Time Adaptation
Joystick-Based	Moderate	Indoor/Flat Terrain	Manual Braking	High	Low
EMG-Based	High	Controlled Environments	Muscle Signal Deviation Alerts	Moderate	Moderate
Gaze-Controlled (CV-Based)	High	Indoor	Obstacle Detection via Vision	Moderate	High
Voice-Controlled + IoT	Moderate	Indoor	Sensor Feedback (Ultrasound, IR)	High	Moderate

BCI-Controlled (EEG)	Low to Moderate	Limited	Thought Signal Error Detection	Low	Low to Moderate
Neuro-Fuzzy Adaptive Systems	High	Variable	Tremor Filtering + Auto Correction	Moderate	High

TABLE 6. COMPARISON OF NAVIGATION AND CONTROL SYSTEMS BY STUDY

Study/Author	Innovation Type	Key Feature	Challenges Highlighted
Desai et al. [16]	AI + Robotics	Autonomous navigation & categorization	Accessibility & cost limitations
Cooper [17]	Microcontroller Feedback	Precision in speed & direction control	Terrain adaptability issues
Alibhai et al. [18]	EMG Interface	Forearm muscle control	Signal noise in outdoor settings
Tian et al. [19]	Monocular Vision Guidance	Visual marker-based indoor navigation	Static marker dependency
Challoo et al. [20]	Neuro-Fuzzy Controller	Tremor compensation in joystick input	Need for individualized calibration
Ghasemi et al. [24]	EEG-Based BCI	Brain-command mobility	Real-time processing delay
Dahmani et al. [26]	Eye-Tracking with CNN	High accuracy gaze detection	Processing optimization required

This comprehensive review demonstrates that while significant strides have been made in enhancing the control systems of smart e-trikes or wheelchairs, several challenges persist. Affordability, precision in uncontrolled environments, sensor fusion optimization, and real-time processing remain active areas for future research. To promote accessibility and user trust, next-generation mobility aids must emphasize reliability, customization, and inclusive design principles.

IV. RECENT ADVANCES AND TECHNICAL REVIEWS ON SMART POWERED WHEELCHAIRS AND E-TRIKES

With approximately 650 million people worldwide facing mobility challenges, the demand for advanced assistive technologies is rising. Traditional wheelchairs often require caregiver assistance, limiting user autonomy. The study proposed by Kumar et al. on "Design and Construction of a Smart Wheelchair" introduces an autonomous model integrating automation for enhanced mobility. It features a humidity sensor for weather adaptation, activating the head mat in cold weather and the foot mat during rain, ensuring user comfort. GPS and ultrasonic sensors were used to detect enhanced security through real time tracking and obstacle detection respectively ultimately leading to safety leading to safe mobility. Along with safety comfort was also a major factor to be addressed. Unlike conventional models, it integrates smart technology that responds to environmental changes and user needs, significantly improving ease of use [27].

Rojas et al. showcased the integration of FPGA and a fuzzy logic-based obstacle avoidance system for electric wheelchairs and electric tricycle. Without the complete dependency on operating system, the proposed hardware system guarantees the real-time processing of data. Use of ultrasonic sensors around the wheelchair provide 360-degree view for detecting obstacles up to 3 meters, leading to a smooth navigation with a high response rate. Along with this fuzzy logic controller were also used to process the data and adjusts movement smoothly for safe navigation. The integration of fuzzy logic and FPGA ensured the independent and reliable as an alternative to software-based navigation solutions [28].

Phichitphon et al. in his research allowed the users to elevate and balance themselves on two wheels which was inspired by iBOT model. Stability challenges in these highly non-linear systems developed a need for the advanced control mechanisms. To address the stability issues, Type-1 and Type-2 fuzzy logic controllers were incorporated into a functional prototype. Sensor noise was reduced by Kalman filter, improving angular position estimation for real-time performance. This proved the benefit of stand-up variants over others guaranteeing stability along with smooth and adaptable movements [29].

With over 1.3 billion disabled individuals worldwide, mobility remains a crucial challenge for independence and quality of life. Many powered wheelchairs require cognitive effort and pose safety hazards, particularly for visually or psychologically impaired users. A real-time LiDAR-based obstacle detection using Cooperative Driving Decision System (CDDS) addressed these issues by implementing joystick inputs that was proposed by Pacini et al. A deep reinforcement learning based motion policy optimizes speed and direction, balancing user autonomy with assisted movements. Despite of design for embedded implementation in real time, the system still faces challenges such as jerky motion and LiDAR’s 2D sensing constraints. The design of an easy-to-use electrification kit connects manual control with autonomous support, ensuring safe and self-reliant mobility [11].

Improvement in the mobility of person with disabilities require safe and effective navigation in powered wheelchairs and electric tricycle. Many individual struggle to navigate complex environments with real time obstacles addressing safety as a major concern. The study mentioned by Teodorescu et al. aimed to improve wheelchair autonomy with the integration of ultrasonic sensors and electronic control boards such as Arduino, for better environmental realization and obstacle avoidance. Simulations in Unity3D validate the feasibility of this approach, demonstrating improved obstacle detection & avoidance without ignoring safety and maneuverability as a major concern. Keeping real-time processing and low computational cost as major factors, this research advances intelligent, user-friendly powered wheelchair and electric tricycle systems. Aligned with

the INTERREG VA FMA ADAPT project, it contributes to ensure safe mobility solutions for individuals with mental, visual, or physical impairments, developing greater independence and confidence [30].

Lecrosniet et al. highlighted the advancements in smart electric wheelchairs plays a crucial role in strengthening independence for mobility in individuals with impairments. An Advanced Driver Assistance System (ADAS) was designed with indoor navigation by integrating object detection and tracking mechanisms. The proposed system employs YOLOv3, a state-of-the-art object detection algorithm, to identify critical objects in indoor movements. Depth analysis is performed using an Intel RealSense camera, enabling the system to determine relationships between the wheelchair and its surroundings. A 3D object tracking mechanism using SORT algorithm implements real time tracking and situational awareness. Due to some constraints of embedded systems, including processing in real-time and memory efficiency, the system is optimized for practical deployment to maintain accuracy [31].

Busaeed et al. studied that over 253 million individuals are affected by visual impairment globally, the need for advanced assistive technologies addressing these impairments became crucial. Visual impairment, the second most prevalent disability after hearing loss, poses significant mobility and navigation challenges. Conventional aids such as white canes have limited functionality, as they primarily detect ground-level obstacles while failing to identify hazards above waist level, increasing the likelihood of injury. To address these limitations, this research introduces LidSonic V2.0, an innovative wearable system integrating LiDAR technology and deep learning to enhance environmental perception and obstacle detection. The second prototype of LidSonic V2.0 has been tested with sighted individuals, with future trials planned for blind and visually impaired users to assess real-world effectiveness [32].

De Vries et al. found that the users of manual wheelchair frequently encounter substantial health challenges, with shoulder pain being one of the most prevalent concerns. Studies indicate that 39% to 71% of wheelchair users experience shoulder pain, which adversely affects their independence, social engagement, and overall quality of life. This study introduces a novel methodology for deriving clinically relevant wheelchair mobility metrics (WCMMs) using IMUs. The system consists of IMUs placed on the wheelchair frame and wheel to collect real-life mobility data [33].

Shabibi et al. studied the advancement of smart wheelchair technology with integration of AI, IoT, and sensor-driven systems to enhance mobility and independence for individuals with disabilities. However, high costs limit accessibility. To address this, a cost-effective IoT-enabled smart wheelchair was developed using an Arduino Nano, featuring Wi-Fi connectivity, obstacle and fall detection, and voice recognition. Testing with 17 participants revealed that increased load reduced speed and motor efficiency, while obstacle detection was effective within a 20 cm range. Despite its affordability, limitations in weight capacity, voice recognition, and location tracking highlight the need for further improvements to enhance usability and accessibility [15].

Y Kim et al. analysed that the development of advanced mobility solutions led to the advancements of intelligent wheelchairs and electric tricycle aligning sensor technologies for advanced and safe navigation. This study presents a system with a vision sensor, ultrasonic sensors, and grid mapping for occupancy in real-time obstacle detection and route mapping. An accuracy of 98.3% was achieved in this experimental setup in environment recognition and a 92.0% success rate in collision-free navigation. Confirmation of safety feature was given by the field tests reducing strain, and increasing user confidence. The study demonstrated the potential of advanced wheelchairs and electric tricycles for providing safer mobility and increased confidence for elderly and disabled [34].

Ceravolo et al. introduced the use of advanced Model Predictive Control (MPC) architecture for more safer navigation in autonomous wheelchairs and electric tricycles. Real time localization was needed to perform obstacle detection and path tracking with the help of robust control algorithms for safer movements. The proposed MPC model is compatible with existing traditional wheelchairs and electric tricycles reducing the need of the hard modifications. The model consisted of actuator dynamics, real time feedback control, sensor-based constraints and cloud data processing for increased user comfort and obstacle detection allowing dynamic trajectory along the path. This approach also prevented deadlock situations, optimizing speed and stability in the motion [35].

Bdirina et al. proposed in his research entitled "Predictive Control for Trajectory Tracking of an Electrical Wheelchair" proposed advanced method of nonlinear predictive control technique to improve maneuverability for safer navigation addressing the issues of accidental risks in traditional powered wheelchairs and electric tricycles. Mathematical modelling Lagrange analysis was done to capture nonlinear dynamics. The proposed research used Taylor expansion of Taylor series to formulate the control law, allowing the wheelchairs and electric tricycles to track the predefined routes adapting to the real time modifications if needed. Despite the success, a limitation was seen due to the high demand of the torque posing limitations on practical implementation [36].

Jung et al. presented a detailed insights of path planning for autonomous wheelchairs and electric tricycles used within the hospital environments. Traditional systems used by the patients often faces the accuracy issues demanding for the advanced navigation system ensuring safety. This study focused on the particular need of hospitals for safer mobility and obstacle avoidance, an algorithm was proposed combining the local and global path planning ensuring proper mobility in the narrow passages and sharp turns. It included caster dynamics, friction control, Hybrid Reciprocal Velocity Obstacle (HRVO) algorithm for collision avoidance, maintains safety of the users. Abrupt control for change in speed and path yielding mechanism were introduced for real world implementation [37].

Nightingale et al. in the study entitled "Predicting Physical Activity Energy Expenditure in Wheelchair Users with a Multisensor Device" analyses the use of Actiheart multisensor device to estimate the expenditure of physical energy for wheelchair users. Traditional methods, such as self-reported questionnaires, are unreliable and accelerometer-based devices often fail to

differentiate between self-propulsion and assisted movement. The study was performed to check whether the individual heart rate calibration (IC) improves physical activity expenditure accuracy as compared to group calibration (GC), relying on standardized algorithm. The study included 15 manual wheelchair users performing various daily activities such as resting, day to day tasks, and wheelchair propulsion at different speeds and angles. Energy expenditure was measured using indirect calorimetry and compared to Actiheart estimations showing significantly higher accuracy. The mean absolute error was lower for IC (16.8%) than GC (51.4%), demonstrating that individualized calibration enhances prediction reliability. Future research should focus on validating these findings in real-world and expanding the study for a broader range of users [38].

Z.T. Al-Qaysi et al. proposed that a new time domain prediction model can improve accuracy, adaptability for real time performance in brain computer interface (BCI) controlled wheelchairs was introduced. Existing BCI driven models have faces some severe challenged like low classification accuracy, higher response time and variation in the EEG signals proved them to be unreliable for real world applications. An advanced generalized time-domain prediction model was introduced for feature extraction and classification techniques for higher precision and adaptability. Experimental datasets were used in adaptive time domain systems to achieve superior classification, better response time and real time analysis [39].

Erturk et al. suggested a major advancement to convert manual wheelchairs into smart devices for mobility with real time obstacle detection and avoidance. Advanced methods for mobility are often expensive, complex to control and need specialized training for accessibility whereas manual methods lack safety making them more prone to accidents. The proposed system integrates a widely used real time motion planning algorithm - Dynamic Window Approach (DWA) along with LiDAR sensors for obstacle detection and find optimal paths maintaining smooth navigation and collision prevention using joystick-based input for real time assistance. The balance between user autonomy and automation supported the implementation in real time. Despite of the proven benefits with multiple experimental setups, it faced a few challenges like detection of stairs and inadaptability to highly dynamic environments [40].

Amrane et al. proposed an electric wheelchair or tricycle with head direction-based navigation. The systems with joystick control were also significant but they posed a major challenge for the people with disability in hand restricting the ease of movements. For resolving this issue, a computer vision-based system with a camera for tracking the head movements was fixed and translated the movements into precise steering commands offering a hand free automated control. This system integrated Artificial Intelligence and computer vision techniques using OpenCV for detecting head rotation angles in real time. By adjusting linear and angular velocities in accordance with the user's head orientation, a differential drive kinematic model ensures accurate wheelchair control. Simulation testing was done which to demonstrate high responsiveness, accuracy and adaptability in real time environment proving the feasibility of computer vision-based wheelchairs and electric tricycles in real world implementation [41].

Iqbal et al. suggested a gesture based controlled electric powered wheelchair that demonstrated to utilize surface electromyography (sEMG) signals helpful for assisting individuals with neuromuscular impairments, such as spinal cord injuries or muscular dystrophy. As mentioned above joystick-based systems have a limitation of accessibility by people with limited hand function, other methods such as brain-computer interfaces (BCI), and eye-tracking systems also faces challenges like low accuracy and higher computational commands. This study proved to be significant for all the other methods using four classification techniques linear regression (LR), regularized linear regression (RLR), decision tree (DT), and multi-class support vector machine (MC-SVM). Support vector machines offered the highest accuracy of (99.05%), providing a user-independent solution. This also supported the real-world implementation. The system was tested on several users and all of them successfully navigated the wheelchair or electric tricycle without assistance and collision. This proved to be a reliable method for improving mobility in people with severe disabilities [42].

Al-Qadasi et al. proposed a method to enable the individuals with impairments relying on Robot Operating System (ROS) framework creating an automated navigation for indoor movements. Using Kinect Xbox sensors for vision-based perception, odometry and LiDAR-based obstacle detection, the system provides accurate path planning. At the initial stages Gmapping SLAM was used for mapping but synchronization and accuracy limitations were observed making a switch to use RTAB-Map and Adaptive Monte Carlo Localization (AMCL). The system followed a predefined navigation goal adjusting the path to avoid obstacles in real time. A Qt-based graphical user interface (GUI) allowed the users to set targets easily, with future plans for AI-driven voice recognition for hands-free control. This hybrid mapping approach boosts accurate path planning and localization, making the system more efficient and adaptable [43].

Olawade et al. suggested the transformation with the involvement of AI driven technologies in improving disabilities is presented significantly in the underlying study. AI systems, such as assistive robotics, smart prosthetics, AI-powered wheelchairs, and speech recognition systems helped to overcome the traditional barriers like healthcare accessibility and receiving timely care. The study presents the application of machine learning models for medical diagnosis, predictive healthcare, and customised rehabilitation therapies, providing early disease detection, automated patient monitoring, and efficient treatment plans. Conversational AI & virtual assistants bridged the gap of communication for individual with speech disability along with the home automation system that provides voice enabled control enhancing quality of life. Some ethical concerns were also addressed like data privacy, lack of inclusive AI designs limits the effectiveness of the AI models [44].

Hussain et al. in his study proposed the alignment of traditional brain computer interface (BCI) design with some advanced techniques to improve mobility and safety for individual with special needs. Conventional BCI controlled electric wheelchairs and tricycles relied on the motor imagery (MI) and EEG signals which were inconsistent to be used. To overrule the limitations this study proposed a mental state aware BCI system that not only converts the signals given by brain into navigation commands but also assess the user's mental and emotional condition by processing EEG responses to psychological sound stimuli,

classifying mental states such as relaxed, alert, or stressed using machine learning models, specifically One-vs-Rest Logistic Regression (OvR-LR). The model achieved prediction accuracy of 74.26%, allowing the wheelchair to adjust its movement based on the user's mental state. Additionally, system incorporated a mechanism that included contingency mechanism to temporarily restrict the movements if the states like high stress or fatigue is detected ultimately reducing the risk of accidents during navigation. With an average response time of 8.4 seconds and 83% accuracy, the system confirms the feasibility of this adaptive BCI based wheelchair or electric tricycle. By addressing both cognitive load and real-time navigation challenges, this study paves the way for more reliable and adaptive BCI-based wheelchair solutions, ultimately enhancing independence and mobility for individuals with disabilities [45].

L. Cui et al. introduced an innovative Cooperative Adaptive Cruise Control (CACC) system designed to enhance the stability, validity, and cybersecurity of Connected and Automated Vehicles (CAVs). Traditional CACC controller-based systems maintain stability in standard conditions but they face potential challenges when dealing with any unexpected circumstances like failure of sensors, cyber-attacks or sudden change in traffic patterns. Whereas All Predecessor Following (APF) topology provides more adaptive system to any unforeseen conditions but faces a stability issue due to the noise generated in communication. This research proposes hybrid CACC controller that combines predecessor and all predecessor techniques to ensure the vehicular movements in a smoother way to facilitate smooth traffic under adverse conditions to protect from all types of cyber-attacks like cyber threats, malware, phishing attempts and any kind of speed fluctuations. A major contribution of the research is the simulation-based validation of the hybrid controller, to reduce the uncertainty, avoids accidents, and smoother vehicle behaviour even under dynamic situations. The research proposed that this hybrid controller provides an effective solution for safe navigation, enhanced efficiency in operations, and monitor traffic flow within intelligent transportation systems [46].

Manero et al. proposed that innovative surface electromyography (sEMG)-based control system for the person with disability conditions like amyotrophic lateral sclerosis (ALS), that leads to limitation of hand movement with inability to operate joystick-controlled powered wheelchairs. This, the study proposes an alternative method which uses sEMG sensors placed on the temporalis muscles, to detect muscle contractions and translate them into accurate steering commands. It was tested on 4 patients aged between 51-69 years, 2 male and 2 female, to evaluate the system's usability. The results showed that three out of four patients who were not able to operate joystick, were able to control the wheelchair using sEMG-based system, reporting enhanced mobility and independence. However, the fourth patient, with partial hand function, found the system less effective compared to a joystick. The study was also tested for bilateral and unilateral control configurations to analyse variations in muscle strength and activation patterns. Overall, the research proposed that sEMG-based wheelchair control is a viable solution for ALS patients with motor impairments providing safety for enhanced mobility [47].

Xiangru et al. introduced a formal control framework for safe and conflict free operation of lane keeping and adaptive cruise control. The research proposed a contract-based design on the basis of assume-guarantee reasoning to define formal safety conditions. A control barrier function (CBF) was developed for set invariance conditions, to ensure the vehicle's lane keeping at a safe distance. Sum-of-squares (SOS) optimization and physics-based modelling were used to derive control barrier function for robust navigation framework. For enhancing real time safety and performance quadratic programming formulation was used to integrate CBF with the traditional performance-based controllers. The proposed model is validated through CarSim vehicle simulations to demonstrate its ability to maintain lane position and safe distances under all types of conditions. The results proved that the hybrid control approach surpass the existing methods and provides the correct solution for concurrent operations [48].

Sankardoss et al. presented an approach to enhance the functionality of electric wheelchairs or tricycles the with the use of Permanent Magnet Direct Current (PMDC) motor. Most of the traditional systems rely on open loop control mechanism leading to inefficient response and speed regulation. To overcome the flaws of open loop, this study introduces closed loop control system to enable the user with speed and direction control of the wheelchair or electric tricycle by using a push button and a graphical user interface for the ease of communication. The proposed system also uses pulse-width modulation (PWM) signals to drive an H-bridge motor driver, along with Proportional-Integral-Derivative (PID) control, Neural Network-based control, and Fuzzy Logic control to ensure better movements in all directions ensuring stability and responsiveness. Three strategies were compared using MATLAB/Simulink simulations and real-time implementation on an ATmega 328P microcontroller. On the basis of the simulation results it was concluded that Fuzzy Logic control outperforms both PID and Neural Network control, providing strong stability, reduced overshoot, and quick response time. The proposed system using advanced AI techniques like neural network and Fuzzy logic demonstrated minimal overshoot, smooth transitions and an intelligent control to adapt in the dynamic environmental conditions [49].

Chotikunnan et al. mentioned that as the demand for the electric wheelchair was growing with time due to aging population and some with neuromuscular disorders limiting the individuals for easy and safe navigation this study demonstrated the integration of PID based motion control system with Mecanum wheels in electric wheelchairs and electric tricycles. This study proposed a system using PID control algorithm, powered by 24V DC battery, controlled using joystick and linked to an Arduino Due microcontroller to optimize the speed regulation omnidirectional system that can move seamlessly. Two control strategies were evaluated Proportional (P) control, which adjusts motor response based on error, and Proportional-Derivative (PD) control, which integrates derivative feedback to reduce oscillations and improve response time along with the Cohen-Coon tuning method to optimize PID gains significantly improving stability and precision [50].

Wang et al. compared three different control strategies including model-based control, proportional-integral-derivative (PID) control, and open-loop control designed to manage the variation in speed and wheel slip in electric-powered wheelchairs and tricycles. Traditional systems using PI controllers face the challenge of optimized performance in real time resulting instability and accidental risk for the individuals with severe disabilities. These limitations were addressed by proposing a real-time model-

based control strategy that integrates a 3D dynamic model to optimize velocity tracking and traction. Onboard computerized controllers, wheel encoders, and inertia sensors were used which were evaluated in the experimental setup to evaluate different surface types and at three different speeds, measuring performance indicators such as speed error, rise time, settling time, and slip coefficient. The setup proved that model-based control system outperforms on both PID and open loop control system with lower speed errors, faster response time and enhanced stability across real time environmental conditions. It also dynamically adjusted torque and velocity reducing slip to on low friction surfaces ensuring smoother and safe movements [51].

Balambica, et al. proposed a wheelchair control system based on Passive Infrared Detector (PID) sensors, to detect hand gestures for controlling wheelchair with hand movements. This solution proved to be more viable and cost effective in contrast to the existing methods. This system uses four PID sensors, an Arduino Uno microcontroller, two motor driver modules, and two brushed DC motors, with a lithium-ion battery. Infrared light reflections were used to operate the system, with the processing through microcontroller for the signals to activate motors and manage the directions. This arrangement made the moves possible in all four directions i.e. forward, backward, left, and right, and it stops automatically when no gesture is detected. The system was tested under various environmental conditions, proving its efficiency in terms of battery life which lasted for 4 to 5 hours per charge. By replacing traditional control mechanisms with a simple, gesture-based interface the proposed system enhances accessibility and independence among the people with disabilities [52].

Batayneh et. al proposed a simpler yet advance system aimed to enhance the maneuverability and tracking accuracy of omnidirectional electric wheelchairs. This system introduced decentralized control system which divides the tasks among independent sub-controllers to manage the wheelchair or electric tricycle's rotational, horizontal, and vertical movements separately. Two artificial intelligence-based control strategies were explored: PD-Fuzzy-P controller and the GA-PID controller. PD-Fuzzy controller combined proportional derivative control fuzzy logic adaptation to adjust the speed in real time with variable environmental conditions. The GA-PID controller, on the other hand, uses a Genetic Algorithm (GA) to optimize the proportional, integral, and derivative gains, improving control stability and system adaptability. MATLAB simulations were done to test the systems on different trajectory paths such as square, circular etc. The accuracy was checked considering the different indicators including mean error and mean square error. The results proved that PD-Fuzzy-P controller outperforms over GA-PID controller providing fast convergence and minimal tracking errors [53].

Tian et al. introduced a self-adjusting fuzzy PID control system that dynamically adjusts the proportional (K_p), integral (K_i), and derivative (K_d) gains in real-time to optimize response time, system stability and turbulence handling. Fuzzy logic with traditional PID controller were combined in a dual axis closed loop system for smooth acceleration, minimal overshoot and powerful resistance for load conditions. Simulations were done in MATLAB/Simulink to show that fuzzy PID controller overperforms as compared to traditional PID controllers [54].

Augie et al. address certain issues like regulating the velocity of an autonomous wheelchair's left and right wheels, authors proposed modified PID algorithm that limits input rate fluctuations to stabilize motion and provide accuracy. Lagrangian mechanics was used to derive the wheelchair's equation and breaking it into kinematics & dynamic models. The kinematics model illustrated the effect of wheel velocities on the overall movement, whereas the dynamic model is responsible for forces and torques on the system. The researchers implemented a standard PID control system to regulate speed, applying the Ziegler-Nichols open-loop tuning method for optimized results. The traditional PID controller faces the problems of overshoot and excessive error accumulation in the systems with abrupt changes. To overcome these problems this study introduced a modified PID algorithm to restrict input rate fluctuations and enhancing response performance [55].

Sankardoss et al., Aralika et al., Shivanand et al., presented a novel approach for optimizing the performance of Permanent Magnet DC (PMDC) motors used in electric wheelchairs and tricycles to enhance motor modelling accuracy. Some limitations of conventional motor parameter estimation techniques like frequency response analysis and recursive least squares, by Genetic Algorithm based optimization method to estimate the electrical, mechanical, and electromechanical parameters of the motor. This study emphasized the importance of accurate motor modelling and how it impacts safety and performance in the electric wheelchairs and tricycles. Three different speed controllers—Proportional-Integral (PI), Proportional-Integral-Derivative (PID), and State Feedback Controllers—in MATLAB/Simulink were used to optimize the motor parameters and performance analysis [56] [57] [58].

Poma et al. introduced an innovative system for individuals with neuromuscular disorder and spinal injuries by using adaptive Proportional-Integral-Derivative (PID) control system that allows accurate seat adjustments ensuring ease of use. The system can be operated in manual and automatic mode to provide flexibility to the users. Inertial Measurement Unit (IMU) was also used in this system which seat tilt angle and ensures that it remains fixed at the angle of user comfort. An Arduino Mega 2560 microcontroller processes the sensor data and applies the PID control algorithm to control the abrupt movements. The system also supported height adjustments upto 15 cm to increase the adaptability of the wheelchair or electric tricycle [59].

Clearesta et al. proposed a Model Reference Adaptive Control (MRAC) framework which aimed to improve the velocity of the wheelchairs and electric tricycles. This study addresses some limitations like controlling of parameters in real-time, speed adjustment and ensuring enhanced performance. The system proposed an adaptive control system by using MRAC to regulate the velocities of the left and right wheels by comparing the rotational speeds, obtained from wheel encoders, with a predefined reference velocity model. The stability of the proposed system is mathematically validated using Lyapunov stability theory, guaranteeing robustness and convergence under real-world environmental conditions. The adaptive controller is able to control the speed variations and disturbances due to delayed ride. It was proposed that integration of additional sensory feedback such as obstacle detection and terrain classification can enhance safety and adaptability thus improving maneuverability and user comfort [60].

Rojas et al. proposed an advanced fuzzy logic-based navigation system aiming to improve maneuverability and obstacle avoidance capabilities in traditional electric wheelchairs and tricycles. Real time sensor data was the main source of processing in traditional systems which sometimes lead to vague decisions in real time. To avoid the misconceptions this system proposes to integrate three ultrasonic sensors to collect real time data, which is processed by Field-Programmable Gate Array (FPGA)-based fuzzy logic controller. By combining static and dynamic fuzzy logic controllers the system is able to decide and make more precise movements also focusing to avoid collisions and path optimization. The comparative results proved that dynamic fuzzy logic controller was more useful when compared to static in terms of smooth movements, reduced collision risk and better adaptability also improving the response time and time delay inputs [61].

Takahashi et al. proposed a system for senior citizens where an innovative braking system was introduced to ensure safe ride, and comfort for the elderly people. This study proposes an innovative fuzzy logic-based regenerative braking system that dynamically adjusts braking force based on real-time evaluation. A step-up chopper regenerative circuit was used to optimize braking power unlike the conventional systems thus reducing jerks and instability due to dynamic acceleration and deceleration. Various driving experiments were conducted with electric powered wheelchairs to validate the effectiveness by providing reducing braking force impact, and enhancing user comfort [62].

Mohammed et al. proposed another advanced nonlinear control strategy which integrates a Fuzzy Logic Controller with a dynamic Lagrange-based model to enhance the efficiency in real world navigation system. Lagrange method was used to derive the relevant mathematical equations which defines kinematic constraints, electromechanical properties, and external forces. Due to the high efficiency, torque and durability, this system also includes Permanent Magnet Synchronous Motors that strengthens the fuzzy logic-based tracking system. Several stages like fuzzification, inference, and defuzzification were included to process the dynamic data and replicate human decision-making capability in uncertain environments. By using error signals and their derivatives, the system ensures precise speed and direction adjustments, leading to stable and adaptive movements in real time for the individuals with physical disabilities [63].

Al-Aubidy et al. introduced an intelligent real-time control system for electric wheelchairs by integrating Brain-Computer Interface (BCI) technology with a Neuro-Fuzzy control system to provide the support to people with severe impairments. This study uses EEG signals to enable hands free operation and also employs an Adaptive Neuro-Fuzzy Inference System to process EEG based user commands. The brain activity is classified into five movement commands—forward, backward, stop, turn left, and turn right—which are then transmitted to a microcontroller. The microcontroller works in close coordination with real time sensor data to ensure adaptability in real time. Decision making accuracy was improved by integrating fuzzy logic and artificial neural networks. The designed prototypes were evaluated in MATLAB Simulink [64].

Zhang et al. provided an analysis of evolution of human machine interaction technologies used in electric powered wheelchairs or tricycles from 1998 to 2020. After a thorough analysis, he stated that brain computer interface proved to be a significant in this field but due to the constraints like high cost and increased complexity their use was limited among the common people. Other methods like voice enabled systems, EEG based machines or eye tracking based systems which used artificial intelligence aimed to balance the user empowerment and smart decisions for enhanced mobility. The bibliometric analysis identifies leading contributors in HMI research, emphasizing the roles of countries such as the USA, China, Japan, and the UK in advancing wheelchair automation and assistive technologies. This study played a crucial role for researchers and developers, outlining potential directions for making human machine interaction driven wheelchairs more accessible and efficient in dynamic environments [65].

Cojocaru et al. proposed a system for the people with visual disabilities and physical disabilities. The system uses computer vision-based control mechanisms including eye-tracking, head movement detection and facial expression recognition allowing users to navigate the wheelchair without any physical inputs. Personalized assessment techniques were provided for the people with severe eye disorders like strabismus and nystagmus which affects accuracy in eye tracking. The system also incorporates the integration of 3D environment mapping and LiDAR-based obstacle detection for both indoor and outdoor environments. Evaluation for different lighting conditions and complex navigation paths, proved it to be a viable solution for diverse users [66].

Parikh et al., Botre et al. proposed a hybrid approach that combined autonomous navigation and human input for smart movements in people with disabilities. Traditional joystick-based systems need physical efforts whereas fully autonomous wheelchairs often lack flexibility limiting the acceptance rate. To address these issues, this study proposes a shared architecture to enable the users for manual and automatic operations in the wheelchairs as and when needed. The intelligent system uses cameras, onboard processing units, sensors, etc allowing for navigation, obstacle detection & avoidance providing flexibility in the real time scenarios. The experimental trial included 50 participants to assess the navigation efficacy, user satisfaction while fully autonomous navigation systems optimized path planning, reducing physical effort providing safety and increasing efficiency [67] [68].

Ponomarjova et al., Biswas et al., examined the use of artificial intelligence and real-time object detection in assistive robotic arms, enabling the users to select tasks based on real-time object detection, streamlining robotic interaction. This study evaluates advanced object detection models, including YOLOv5 and YOLOv8, comparing their accuracy, processing speed, and real-time usability. The proposed AI based system allows real time decision making with the modern design including start & stop buttons reset functions, and adjustable speed settings, ensure reliability and prevent operational errors. The system also incorporates advanced multimodal control integration, including eye tracking and voice commands, to accommodate users with different physical abilities [69] [70].

Table 7 provides a comparative analysis of different electric tricycles or smart wheelchairs, emphasizing their control strategies, functional outcomes, and associated challenges.

S.No.	Electric Tricycle / Wheelchair	Control Methodology	Functional Benefits	Challenges
1	Smart Wheelchair with Automation	Uses automation for mobility, integrates humidity sensors for weather adaptation, ultrasonic sensors for obstacle detection, and GPS for security [27]	Enhances user autonomy, ensures comfort, improves safety with GPS tracking	Dependence on external power sources, increased complexity in maintenance
2	FPGA-Based Obstacle Avoidance Wheelchair	Uses fuzzy logic-based obstacle avoidance with FPGA technology and 360-degree ultrasonic sensor coverage [28]	Real-time processing without OS dependency, precise navigation decisions, high response rate	Requires complex tuning, limited to ultrasonic sensor range
3	Stand-Up Wheelchair	Employs Type-1 and Type-2 fuzzy logic controllers with a Kalman filter for stability and smooth movement [29]	Improves user posture, enables height adjustment for social interactions	Stability challenges, high power consumption
4	Cooperative Driving Decision System (CDDS) Wheelchair	Uses LiDAR-based obstacle detection combined with joystick inputs and deep reinforcement learning (DRL) for navigation [30]	Reduces cognitive effort, improves navigation safety for visually impaired users	Requires training data, sensor limitations in extreme conditions
5	Brain-Controlled Wheelchair	Uses EEG signals and brainwave patterns to control movement [31]	Allows hands-free control, beneficial for individuals with severe disabilities	High cost, requires extensive training, potential inaccuracies in signal interpretation
6	Voice-Controlled Wheelchair	Uses speech recognition technology to interpret voice commands for movement [32]	Hands-free operation, accessible for users with limited motor function	Background noise interference, accuracy issues with speech recognition
7	Gesture-Controlled Wheelchair	Uses sensors to detect hand or head gestures for movement control [33]	Intuitive control for users with speech impairments, enhances independence	Requires learning curve, may have limited gesture recognition accuracy
8	Eye-Tracking Wheelchair	Uses camera-based tracking of eye movements to guide wheelchair movement [34]	Beneficial for users with severe motor impairments, minimal physical effort required	Expensive technology, potential calibration issues
9	Model Predictive Control (MPC) Wheelchair	Uses nonlinear predictive control strategy to enhance trajectory tracking and maneuverability [35]	Improves navigation accuracy, reduces risk of accidents, adapts to disturbances	High torque demand, computationally intensive optimization
10	Predictive Control for Trajectory Tracking	Applies Taylor series expansion and quadratic optimization to regulate angular position and velocity [36]	Ensures smooth movement, effective for obstacle avoidance	Requires high computational resources, energy efficiency concerns
11	Path Planning for Autonomous Electric Wheelchair	Combines global and local path planning with real-time obstacle avoidance [37]	Enhances navigation in hospital environments, eliminates need for manual operation	Complexity in handling narrow corridors, dependency on predefined paths
12	Physical Activity Prediction Wheelchair	Uses motion sensors and machine learning models to predict user activity levels [38]	Helps with adaptive assistance, enhances rehabilitation monitoring	May not generalize well across different users
13	Generalized Time Domain Prediction Model	Uses real-time sensor fusion to predict movement patterns [39]	Improves responsiveness, reduces reaction time in dynamic environments	Requires precise calibration, computationally expensive
14	Driving Assistance System	Integrates obstacle detection with automated emergency braking [40]	Enhances safety, reduces collision risks	Sensor limitations in low-light conditions, potential false positives
15	Mobility Enhancement System	Uses AI-based navigation aids for better maneuverability [41]	Increases accessibility, reduces strain on caregivers	High cost, dependent on robust AI models
16	Adaptive Control Wheelchair	Implements adaptive control strategies based on user behaviour and terrain feedback [42]	Improves stability, adjusts to environmental conditions	Complexity in implementation, requires real-time processing
17	Smart Wheelchair with Automation	Uses automation for mobility, integrates humidity sensors for weather adaptation, ultrasonic sensors for obstacle detection, and GPS for security [43]	Enhances user autonomy, ensures comfort, improves safety with GPS tracking	Dependence on external power sources, increased complexity in maintenance
18	FPGA-Based Obstacle Avoidance Wheelchair	Uses fuzzy logic-based obstacle avoidance with FPGA technology and 360-degree ultrasonic sensor coverage [44]	Real-time processing without OS dependency, precise navigation decisions, high response rate	Requires complex tuning, limited to ultrasonic sensor range
19	AI-Based Navigation System	Employs AI-driven navigation for improved path planning and real-time obstacle detection [45]	Enhances efficiency, reduces human intervention, learns from user behaviour	High computational requirements, dependency on robust training data

20	Multi-Sensor Fusion Wheelchair	Integrates LiDAR, ultrasonic, and camera sensors for precise environmental awareness [46]	Improves safety, seamless indoor-outdoor transition	Complexity in sensor fusion, increased hardware costs
21	Semi-Autonomous Wheelchair	Combines user control with autonomous assistance for obstacle avoidance [47]	Provides balance between manual and autonomous control, enhances user confidence	May not be fully reliable in highly dynamic environments
22	IoT-Enabled Wheelchair	Uses IoT connectivity for remote monitoring and data collection [48]	Allows remote assistance, improves predictive maintenance	Requires stable internet connection, potential cybersecurity risks
23	Stand-Up Wheelchair	Employs Type-1 and Type-2 fuzzy logic controllers with a Kalman filter for stability and smooth movement [49]	Improves user posture, enables height adjustment for social interactions	Stability challenges, high power consumption
24	Brain-Controlled Wheelchair	Uses EEG signals and brainwave patterns to control movement [50]	Allows hands-free control, beneficial for individuals with severe disabilities	High cost, requires extensive training, potential inaccuracies in signal interpretation
25	Hybrid Control Wheelchair	Combines multiple control mechanisms such as EEG, voice, and gestures [51]	Provides flexibility and adaptability based on user preferences	Higher complexity, increased maintenance requirements
26	Gesture-Controlled Wheelchair	Uses sensors to detect hand or head gestures for movement control [52]	Intuitive control for users with speech impairments, enhances independence	Requires learning curve, may have limited gesture recognition accuracy
27	Eye-Tracking Wheelchair	Uses camera-based tracking of eye movements to guide wheelchair movement [53]	Beneficial for users with severe motor impairments, minimal physical effort required	Expensive technology, potential calibration issues
28	Voice-Controlled Wheelchair	Uses speech recognition technology to interpret voice commands for movement [54]	Hands-free operation, accessible for users with limited motor function	Background noise interference, accuracy issues with speech recognition
29	AI-Enhanced Navigation Wheelchair	Uses deep learning algorithms for dynamic path planning and real-time obstacle avoidance [55]	High accuracy in complex environments, improves user confidence	Requires extensive training data, computationally expensive
30	Multi-Sensor Fusion Wheelchair	Integrates LiDAR, ultrasonic, and camera sensors for precise environmental awareness [56]	Enhances safety, allows seamless indoor-outdoor transitions	Sensor fusion complexity, increased hardware costs
31	Haptic Feedback Wheelchair	Incorporates haptic feedback for enhanced user interaction and obstacle detection [59]	Provides real-time sensory feedback, improves user experience	Requires additional hardware, possible sensory overload
32	Internet-Connected Smart Wheelchair	Uses IoT connectivity for remote diagnostics and monitoring [60]	Enables remote assistance, facilitates predictive maintenance	Requires stable internet connection, potential cybersecurity risks
33	Gesture-Controlled Wheelchair	Uses sensors to detect hand or head gestures for movement control [61]	Intuitive control for users with speech impairments, enhances independence	Requires learning curve, may have limited gesture recognition accuracy
34	Eye-Tracking Wheelchair	Uses camera-based tracking of eye movements to guide wheelchair movement [62]	Beneficial for users with severe motor impairments, minimal physical effort required	Expensive technology, potential calibration issues
35	AI-Enhanced Navigation Wheelchair	Uses deep learning algorithms for dynamic path planning and real-time obstacle avoidance [63]	High accuracy in complex environments, improves user confidence	Requires extensive training data, computationally expensive
36	Multi-Sensor Fusion Wheelchair	Integrates LiDAR, ultrasonic, and camera sensors for precise environmental awareness [64]	Enhances safety, allows seamless indoor-outdoor transitions	Sensor fusion complexity, increased hardware costs
37	IoT-Enabled Wheelchair	Uses IoT connectivity for remote monitoring and data collection [65]	Allows remote assistance, improves predictive maintenance	Requires stable internet connection, potential cybersecurity risks
38	AI-Based Navigation System	Employs AI-driven navigation for improved path planning and real-time obstacle detection [66]	Enhances efficiency, reduces human intervention, learns from user behaviour	High computational requirements, dependency on robust training data
39	Haptic Feedback Wheelchair	Incorporates haptic feedback for enhanced user interaction and obstacle detection [67]	Provides real-time sensory feedback, improves user experience	Requires additional hardware, possible sensory overload
40	Internet-Connected Smart Wheelchair	Uses IoT connectivity for remote diagnostics and monitoring [69]	Enables remote assistance, facilitates predictive maintenance	Requires stable internet connection, potential cybersecurity risks

V. AI Operated Speed and Safety Control for Smart Wheelchairs and Electric Tricycles

The proposed architecture aims to enhance mobility, stability, and accessibility for physically disabled elderly individuals. An intelligent control unit, user enabled input mechanism, microcontroller such as Arduino or Raspberry Pi to process user commands and control speed using adaptive control algorithms were integrated to work in real time. To ensure the optimized acceleration, deceleration, braking to minimize sudden jerks on different road conditions, fuzzy logic and proportional integral derivative were combined.

The system comprises of multiple user input options considering different forms of physical disabilities. Traditional method comprises of a joystick enabling easy navigation but for the users with limited hand functionality an EEG based, brain computer interface based or voice controlled based system provided hands free control. The electric powered system consists of a brushless DC motor, controlled by a pulse width modulation for better speed control. It also comprises of regenerative braking technology to recover energy during braking to improve the battery efficiency.

A high-capacity rechargeable lithium-ion battery is used to supply energy to the motor control unit, and auxiliary safety features. Overcharging condition is also controlled by a battery management system to ensure optimal power distribution and enhance system reliability. Integration of ultrasonic and LiDAR sensors was done for obstacle detection and avoidance. The sensors continuously monitor the dynamic environment to automatically adjust the speed and avoid any kind of collisions. Furthermore, anti-tip wheels and an active stability control system prevent the tricycle from overturning on uneven surfaces. Gyroscopic sensors and accelerometers detect sudden tilts or uncontrolled movements in case of an emergency.

User safety and accessibility is enhanced by low step frame feature for effortless entry and exit. The seat is also cushioned with a backrest and adjustable armrest providing convenience to the users for long use. The system also integrates GSM and Wi-Fi connectivity enabling real time tracking and providing caretaker support as and when needed through a mobile application. Caregivers can track location, speed and system status in case of any breakdown or abnormality. Continuous supervision can be maintained to enhance safety for elderly people.

The overall aim is to provide a smart electric tricycle or wheelchair capable of automatic, adaptive and safe mobility for the individuals with impairments. Real time input and processing is needed to detect obstacles in dynamic road conditions and speed optimization for smooth navigation. The use of AI driven system with real time data monitoring and user-friendly designs make this a highly effective solution for the need of the elderly people with disabilities. The block diagram for AI-Based speed and stability control framework for e-trike and wheelchair is shown in figure 1. This architecture bridges the gap between conventional mobility aids and intelligent assistive transportation, providing a reliable and user-friendly alternative for independent movement.

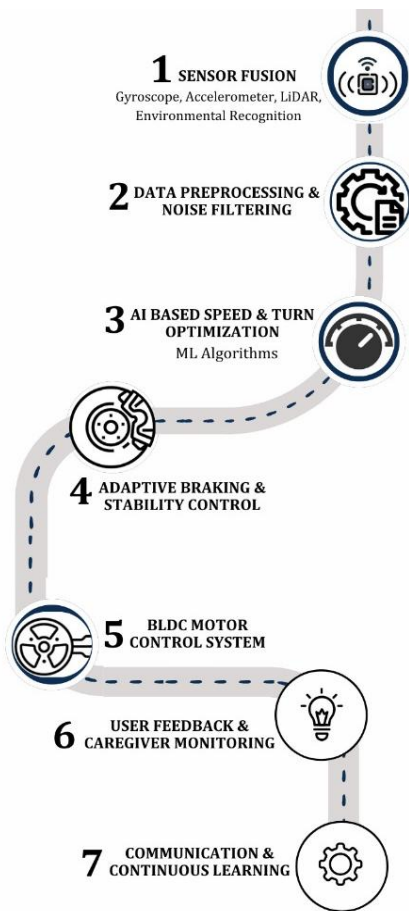


Figure 1: AI-Based Speed and Stability Control Framework for E-Trike and Wheelchair

CONCLUSION

The detailed review presented in this paper has extensively examined the mechanisms for speed control and the technologies used in electric tricycles or smart wheelchairs, focusing on increasing stability, safety and independent mobility of elderly and disabled persons. This review article presents the study of selected high-quality research articles and follows a PRISMA based methodology. It observed the various speed control techniques including conventional PID, fuzzy logic, neural network and adaptive AI-based controllers presenting their benefits and drawbacks.

It has been reported that while using conventional controllers like PID which provides basic stability and are rigid to adapt dynamic terrains and conditions posed by user marks serious drawbacks. On the other hand, fuzzy logic and hybrid intelligent systems presents better in non-linear and dynamic environment resulting in better tracking, obstacle avoidance and regulating speed of the electric tricycles or smart wheelchairs. In addition to this, sensor based controlled techniques like vision sensors, ultrasonic sensors and LiDAR presented better result specially at turning locations. Emerging innovations such as brain-computer interfaces (BCIs), electromyography (EMG)-based control, and AI-enhanced predictive models are poised to redefine human-device interaction by enabling intuitive, personalized control schemes.

Comparative analyses presented in Tables 5 and 6 highlight the technological heterogeneity in existing models and point toward specific challenges like high computational costs, sensor fusion inconsistencies, user adaptability, and affordability constraints. Additionally, a critical gap is identified in optimizing speed control at critical junctions like sharp turns and crowded urban environments, where most systems underperform in maintaining user stability and path accuracy.

The review also emphasizes the urgent need for low-cost, modular, and scalable speed control systems to facilitate widespread adoption in developing regions. Ethical design principles, inclusive user testing, and regulatory compliance were recognized as essential for translating these innovations into commercially viable solutions. Figure 4 illustrates a conceptual AI-driven architecture for future smart mobility systems, offering an integrated view of perception, decision-making, and actuation subsystems.

In conclusion, this paper contributes valuable insights by bridging existing technical gaps and outlining the roadmap for future innovations in intelligent assistive mobility. The findings underscore the importance of adaptive, context-aware speed control mechanisms that not only enhance physical mobility but also empower users with greater confidence, autonomy, and safety. Future research should focus on developing robust real-time systems with hybrid control strategies, multimodal user interfaces, and cloud-based learning architectures to facilitate continuous performance improvement and user personalization in diverse operating environments.

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DISCLOSURE OF INTEREST

The authors (Mr. Gaurav Sahu, Dr. Bhausaheb Ashok Botre, and Dr. Vishant Gahlaut) declare that we have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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